DETERMINATION OF EFFICIENCY AND ENERGY RESOLUTION OF SCINTILLATION DETECTOR IN 511-1332 keV ENERGY RANGE

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Abstract

The most radiation detection method is based on the gamma – ray Spectrometry measurement, which is widely used in different fields. To obtain accurate analytical results in an experimental research, quality control of the detection system is important. Detection efficiency and energy resolution of NaI(Tl) scintillation detector are fundamental parameters for detection system. In this work, detection efficiency and energy resolution of 2″ x 2″ NaI(Tl) detector were experimentally measured using ^{22}Na, ^{60}Co and ^{137}Cs standard radioactive sources at the energy range of 511 keV to 1332 keV.

Keywords: Scintillation detector, Energy resolution, Detection efficiency, Gamma ray spectrometry

Introduction

In gamma ray Spectrometry measurements, NaI (Tl) scintillation detectors have been widely used in variety of different fields such as neutron activation analysis technique, nuclear reactor technology, elemental analysis of different alloys, nuclear medicine, industry, radiation protection and environmental applications [Vrkiye Akar Tarim, Orhan Gurler, 2018].

Especially, NaI (Tl) detectors used to make qualitative and quantitative analysis with various natural and artificial radionuclides. In each application, the accurate values of detection efficiency and energy resolution of NaI(Tl) detector is essential in nuclear investigations and in all experimental studies that measure radiation.

Every resolution and detection efficiency system depends on the energy of gamma rays, detector type, density and size, detector and source dimensions, detector and source geometry and different detector operating parameters [Karadeniz and Vurmaz,2017].

The necessary calibration corrections were applied to improve the quality of radioactivity measurements. In this study, efficiency and energy resolution of the 2″x2″ NaI(Tl) detector were measured experimentally at 511.0 keV, 661.66 keV, 1173.23 keV,1274.60 keV and 1332.48 keV gamma ray energies obtained from ^{22}Na,^{60}Co and ^{137}Cs standard radioactive isotopes.

Materials and Method

Experimental Procedure

In this research work, NaI(Tl) scintillation detector (Type 38B51 2″x 2″), multi-channel analyzer (13727 – 99), serial S2AA6691 and high voltage power supply 1.5 kV DC (09107 – 99) were used. By using the measure software for the spectrum analysis; peak searching, peak area calculation, energy calculation, peak evaluation and data acquisition. To reduce the background of detecting system, the detector is shielded with 3 cm thick lead on all sides.

Block diagram for γ- ray spectroscopy system with NaI(Tl) detector is shown in Figure 1. The three different standard radionuclides ^{22}Na, ^{60}Co and ^{137} Cs were used in this work. The distance between source and detector is 4 cm. Optimum voltage is 650 V and kept constant throughout the experiment. The time taken for data acquisition was 300 seconds or 5 minutes.

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Table 1 showed gamma ray emission probabilities per decay, half-life, decay fraction and present activity for all radioisotope sources used in this work. The energies, emission probabilities and decay fractions were taken from International Atomic Energy Agency (IAEA) Nuclear Data Services [Vrkiye Akar Tarim,et al,2018].

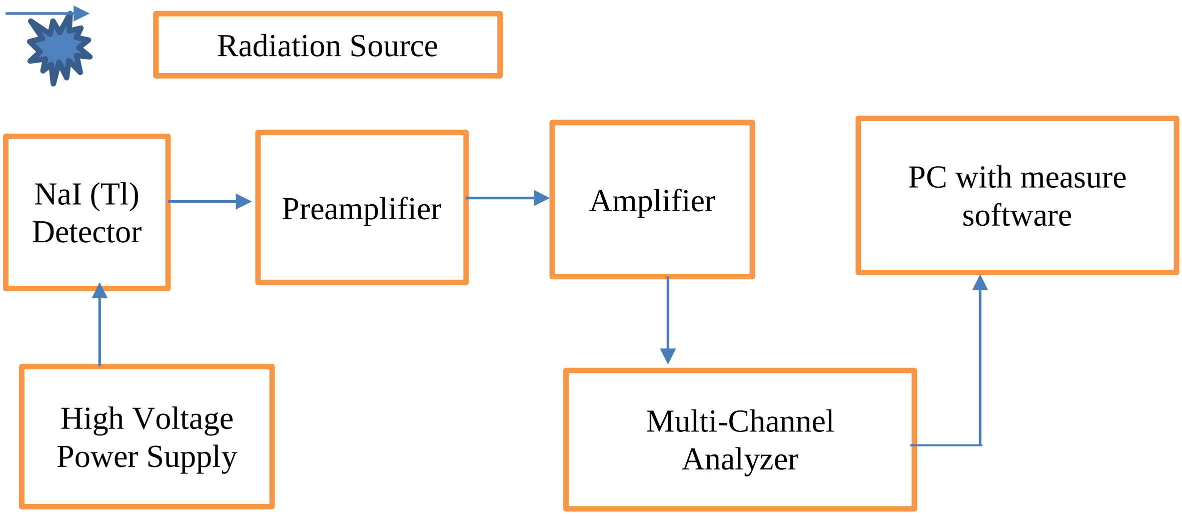

Figure 1 Schematic diagram of the experimental setup

Table 1 Specifications of the radionuclides

Nuclide	Gamma Energy (keV)	Half-life (year)	Present Activity (µ Ci)	Decay fraction (*f*)	Emission Probability (%)
^{22}Na	511	2.6	2.0114	0.99	99.00
	1275			0.9994	99.94
^{137}Cs	662	30.1	4.6218	0.851	85.00
^{60}Co	1173	5.27	0.6381	0.9985	99.85
	1332			0.9986	99.982

Energy Calibration

Firstly, the detector system was calibrated before using in measurement of gamma radiation detection. In this research work, the energy calibration is performed by measuring 661.66 keV photopeak from ^{137}Cs and the 1173.23 keV and 1332.48 keV photopeak from ^{60}Co standard sources. Acquire the spectra for both the sources for preset time is 300 seconds. For the 1024-channel setup, MCA setting gain level is 1, offset [%] is 5, interval width [channel] is 1. Do not change the calibration process of NaI(Tl) detector in the whole experiment. Energy calibration of the NaI(Tl) detector was occasionally made to establish the linking between the energy, channel number, detector efficiency, energy resolution and in order to convert channel number to energy scale. Figure 2 shows energy calibration curve which is plotted by energy of gamma – rays with the pulse – height corresponding to the photo – electrons from different gamma sources. In this diagram, the pulse – height is proportional to the energy and use to correlate channel number to energy for any source. The measured typical gamma ray spectrum for ^{137}Cs, ^{60}Co and ^{22}Na radionuclides are shown in Figure 3, 4 and 5.

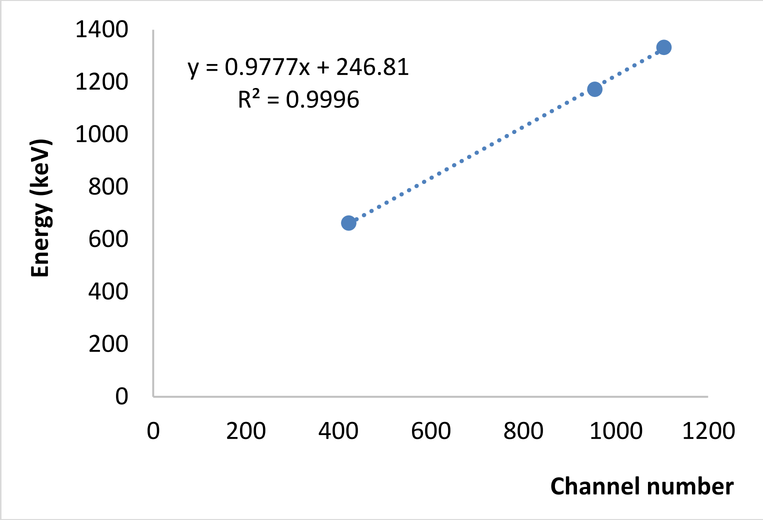

Figure 2 The energy calibration curve for NaI(Tl) using ^{60}Co and ^{137}Cs nuclides

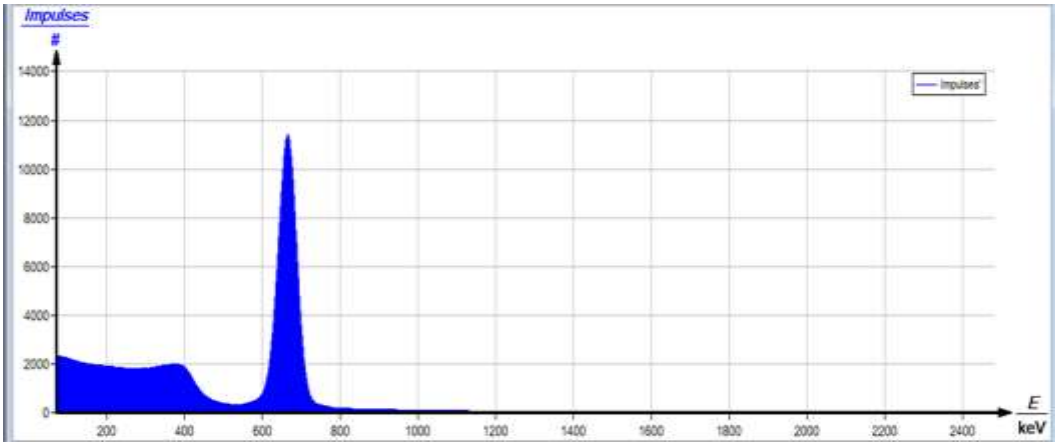

Figure 3 Typical ^{137}Cs spectrum measured using NaI(Tl) detector

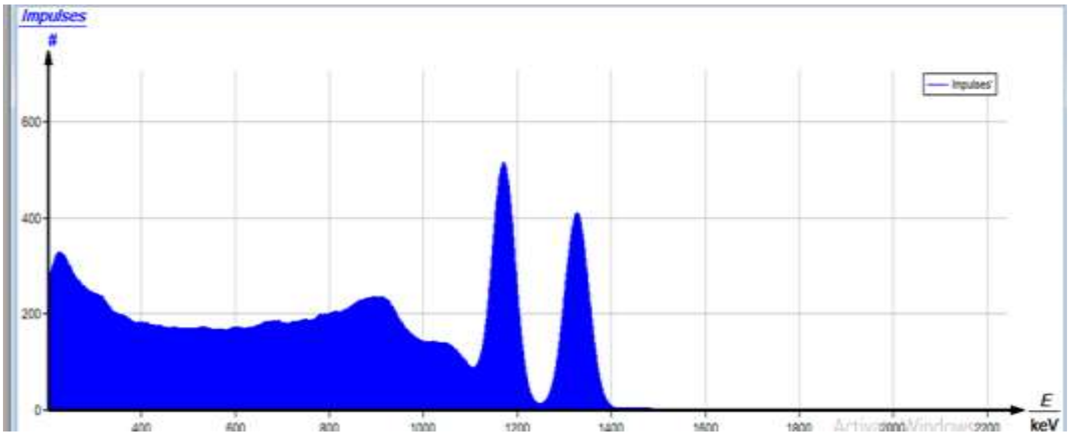

Figure 4 Typical ^{60}Co spectrum measured using NaI(Tl) detector

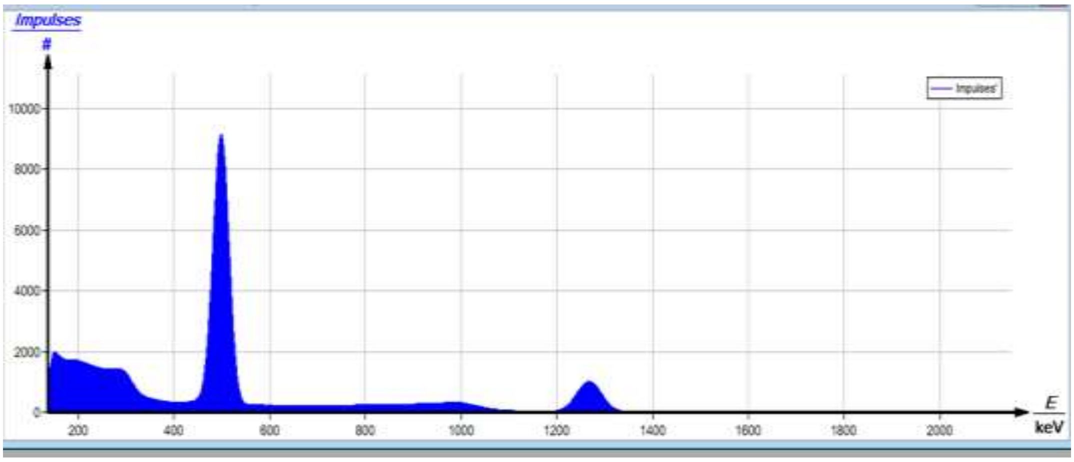

Figure 5 Typical ^{22}Na spectrum measured using NaI(Tl) detector

Energy Resolution

Energy resolution is a very important parameter to avoid the interference between two gamma ray energies from gamma source and it is the ability of the detector to accurately determine the energy incoming gamma radiation. Energy resolution depends on the detector type and the energy of gamma photons and allows a detector to differentiate between primary photons and Compton scatter photons. The experimental formula for determining the percent energy resolution is

$$\%\, Energy\, resolution = \frac{E_2 - E_1}{E_0} \times 100$$

$E_2 - E_1 = \Delta E$ is full Width Half Maximum (FWHM), E_0 is gamma energy. The FWHM is denoted by the symbol "r" and it is the width of the Gaussian distribution at half of its maximum position. The gamma ray spectrums were counted for three standard sources and from which FWHM is estimated by using measure software. The experimental data is given in table 2 [Pansare, Ansari, et al,2016].

Detector Efficiency

$$DE = \frac{D}{N} \qquad \text{(or)}$$

$$\varepsilon(\%) = \frac{A_{out}}{A_{in}} \times 100$$

DE is the detector efficiency; D is the number of pulses recorded by the detector and N is the number of radiations emitted by the source. A_{out} is the number of counts recorded by the detector and A_{in} is the number of gamma rays falling on detector. A_{in} can be calculated by using the equation,

$$A_{in} = \frac{r^2}{4d^2} \times A_t.$$

$\frac{r^2}{4d^2}$ is geometrical factor, d is the distance between source and detector, r is the radius of detector, A_t is activity of radioactive nuclide and it can be calculated by using equation,

$$A_t = A_0\, e^{-\lambda\, t}.$$

A_0.is initial activity at t = 0, λ is decay constant and t is the time difference between experiment date and source manufacture date [Pansare, Ansari, et al,2016].

Results and Discussion

The detection efficiency of the NaI(Tl) detector was determined experimentally at 511,662,1173,1275 and 1332 keV gamma ray energy emitted by ^{22}Na, ^{60}Co and ^{137}Cs radioactive sources. The measured results were shown in Table 2 and have been displayed as a function of gamma energy in Figure 6. From Figure 6, the detector efficiency is high in the low energy region and decreases with increasing energy. This is because of decreased in the number of photoelectric events and increased Compton scattering when energy increases. In Figure 6, the experimental data points were fitted a second-degree polynomial equation using measure software. It gives a good description with the correlation between the efficiency values and the gamma ray energies, which is about $R^2 = 0.9984$.

Another important parameter for detection system is energy resolution, obtained from the full width at half its maximum (FWHM). The values of FWHM and energy resolution for the NaI(Tl) detector is listed in Table 2. Figure 7 is displayed as a function of gamma ray energy with measured energy resolution of the NaI(Tl) detector. From this figure, the energy resolution of the NaI(Tl) detector decreased with increasing in gamma energy.

Table 2 Experimental results for efficiency, FWHM and resolution of NaI(Tl) detector

Nuclide	Gamma Energy(keV)	Efficiency (%)	FWHM (keV)	Resolution (%)
^{22}Na	511	9.35	42.02152	8.22338
^{137}Cs	662	7.42	47.65	7.19788
^{60}Co	1173	3.32	59.08165	5.03679
^{22}Na	1275	2.51	58.87	4.618
^{60}Co	1332	2.458	58.329	4.37905

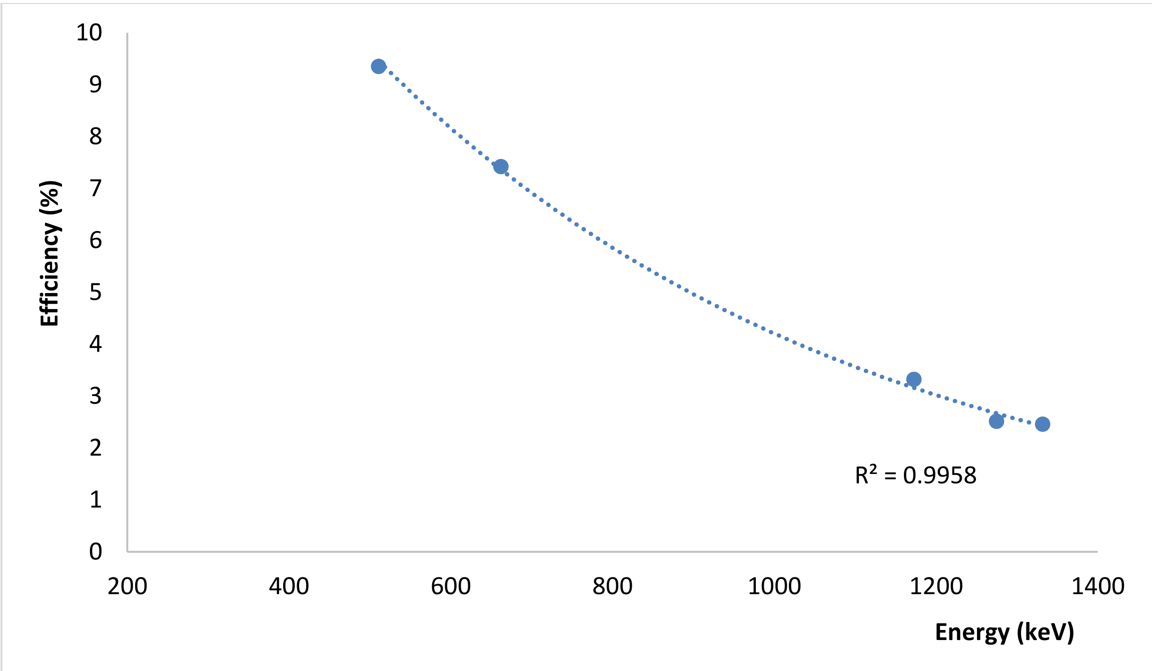

Figure 6 Variation of detector efficiency as a function of different energies

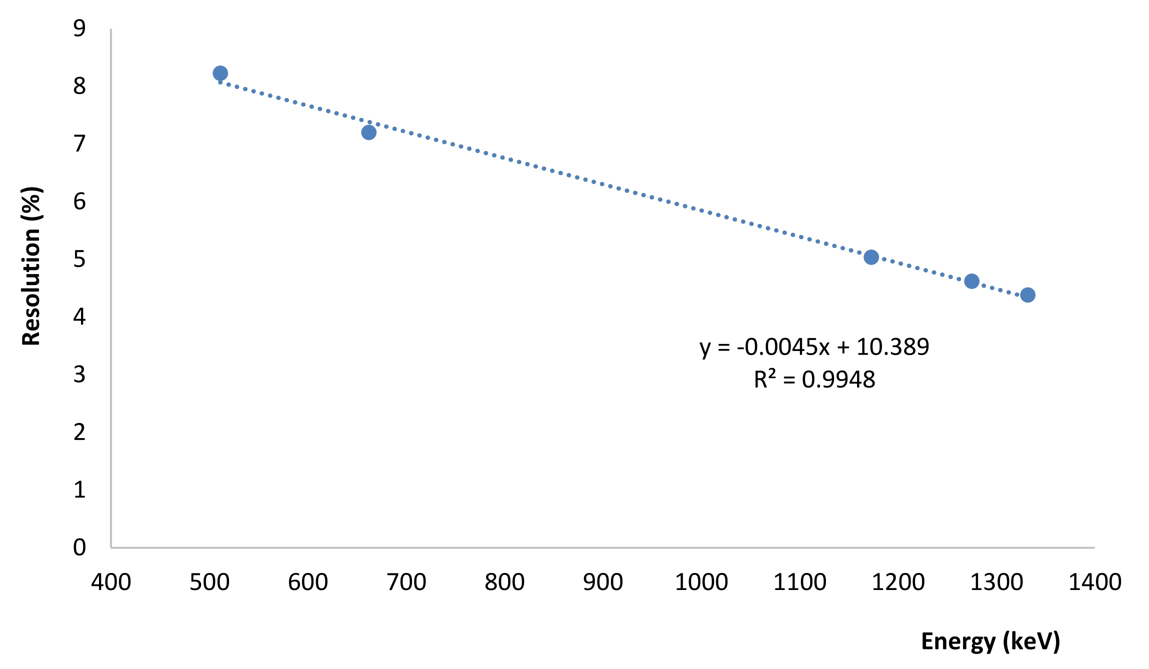

Figure 7 Energy resolution of the NaI(Tl) detector

Conclusions

In this research work, detector efficiency and energy resolution of the NaI(Tl) detector was determined experimentally by using gamma ray spectrometry measurement in 511 keV to 1332 keV energy range. The values of detection efficiencies for these energies are 9.35%, 7.42%, 3.32%, 2.51% and 2.458% respectively. The values of energy resolution for these five energies are 8.22338%, 7.19788%, 5.03679%, 4.618% and 4.37905%. The results were found that the resolution of the detector was directly proportional to the energy of gamma ray and its efficiency was exponentially proportional to the gamma ray energy. These two factors depend on the gamma ray energy, detector type, size and other detector parameters. So, determination of detector efficiency and energy resolution of the NaI(Tl) detector is essential to specify the quality for the results of gamma ray spectrometry measurements.

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